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Research paper

Effect of Curing Method on Concrete with Palm Oil Fuel Ash as a Cement Replacement

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Abstract

In this paper, the effect of different curing methods on the strength of concrete with palm oil fuel ash as a cement replacement is investigated. An experimental program was carried out to study the effect of five different curing methods, i.e., water curing (WC), air curing (AC), plastic-wrapped curing (PC), oven and water curing (OWC), and oven and air curing (OAC), on the compressive and flexural strengths of palm oil fuel ash concrete (POFA20), where 20% of the cement was replaced by palm oil fuel ash. The results obtained from this investigation showed that POFA20-WC has the highest compressive and flexural strength, whilst POFA20-AC has the lowest at the age of 28 days. Both of the POFA20-OWC and POFA20-OAC have the highest compressive and flexural strength at the age of 3 days. The results emphasize the positive effect of oven curing procedure to achieve high compressive and flexural strength at early stage. However, the rate of hydration started to decrease at later stages, which leads to much lower rate of gaining strength in POFA20-OWC and POFA20-OAC. Water curing method is thus recommended in the construction industry except for extraordinary requirements and/or circumstances.

Keywords: *Cement replacements; concrete; curing methods; palm oil fuel ash (POFA).*

1. Introduction

In recent years, a series of investigations have been carried out on the use of agrowaste ashes as a partial replacement for cement in concrete and palm oil fuel ash is one of them, see, e.g., references [1-12], not to mention many others. Agrowaste ashes can be used as a pozzolanic material due to the high amount of silica in amorphous form inside. Palm oil fuel ash is a type of pozzolan whose chemical composition is found to have a large amount of silica [13,14] and thus, has high potential to be used to partially replace cement in concrete. During the hydrated phase, the silica content in palm oil fuel ash reacts with calcium hydroxide (Ca(OH)) and this pozzolanic reaction produces more calcium silicate hydrate (C-S-H), which is a gel compound [15]. This whole process contributes to the performance of concrete [16].

Among the first investigations on POFA concrete is the study carried out by Tay [17], where a laboratory test was conducted with ordinary Portland cement has been replaced by 10% to 50% of palm oil fuel ash. Generally, the replacement of cement with palm oil fuel ash causes the compressive strength of concrete to be lower than the normal concrete with the same mix design. Aside from the 10% of ash used, it was found that the compressive strength of the concrete, tested at various ages, decreased proportionally with the increase in the replacement of palm oil fuel ash from 20% to 50%. Thereafter, Tangchirapat et al. [12] concluded that 20% replacement of cement with palm oil fuel ash gives the highest compressive strength. In addition, it was found that with high degree of fineness of palm oil fuel ash, concrete could reach the compressive strength of a normal concrete. This could be achieved by grounding and sieving the ash to the median particle size below 15.9μm. The finer is the ash, the higher strength the concrete could achieve. Tangchirapat et al. [11] conducted another test and found out that the 70 MPa high strength concrete can be produced using high degree of fineness of palm oil fuel ash due to its pozzolanic property. The result revealed that high strength POFA concrete has a rather higher compressive strength than the normal concrete. A similar research [6] showed the same result and by adding some silica fumes, the compressive strength of POFA concrete would increase due to the filler effects and the increase in the extent of the pozzolanic reaction. Another research [3] showed that when 50% of cement replacement with 2% of super plasticizer, the target strength could be reached. In an investigation by Ahmad et al. [15], the 15% POFA concrete achieved a higher compressive strength than the normal concrete at the age of 3 days and 7 days.

The need for proper curing of concrete cannot be overlooked as it has a large impact on the mechanical properties of the hardened concrete such as compressive strength, flexural strength and durability. Therefore, many investigations -on the effect of different curing conditions for normal concrete have been carried out, see, e.g., references [18-23] and the references cited therein. Among the conventional curing methods are: water curing (WC), air curing (AC), plastic-wrapped curing (PC), oven and water curing (OWC), and oven and air curing (OAC).

In the modern construction, time saving is essential and as a result, a lot of precast members are being used on site. Precast concrete needs a reasonable high early strength in order to be transported to the site and it is necessary to make sure that the concrete is strong enough to support the workers' loads who are going to work on it and to support the loads from further structural members. Sometimes, high early strength cannot be gained through the normal curing methods such as WC but only through other curing methods. In order to accelerate the early strength of concrete, a theory has to be followed. The initial compressive strength is directly related to the maximum temperature of the curing, duration of the curing and the rate of hydration in concrete. The increase in strength is due to the extended hydration. This happens because Calcium-Silica-Hydrate, C-S-H gel, which is the most important binding phase in concrete, is formed quicker than in conventional water curing or air curing methods due to the presence of excessive humidity and temperature. The existing literature is mainly focused on the effect of different curing regimes on normal concrete. Hence, this study attempts to breach this research gap by investigating the effect of different curing methods on the compressive and flexural strengths of concrete with palm oil fuel ash as a cement replacement.

2. Methodology

2.1. Materials

Orang Kuat ordinary Portland cement was used in this study and it was obtained from YTL Cement Berhad, Malaysia. The cement used is CEM I 42.5N and is certified to MS 522-1:2007 (EN 197-1:2000). The chemical composition and physical properties are shown in Table 1 (reproduced from supplier brochure).
Local river sand was used as fine aggregate which has fineness modulus of 2.56. The density of the fine aggregate is 1019 kg/m^3 and its specific gravity is 1.02. Crushed limestone with nominal size ranges from 5mm to 20mm was used as coarse aggregate. The density of the coarse aggregate is 2552 kg/m^3 and its specific gravity is 2.55.
Palm oil fuel ash was collected from Jugra Palm Oil Mill Sdn. Bhd. It had been dried and was then brought to the laboratory to be sieved (sieve opening size of 300µm). 300µm size of palm oil fuel ash was used instead of finer one because the main objective of this study is to investigate the difference in strength of the palm oil fuel ash concrete under different curing regimes rather than to determine the ultimate strength the concrete can achieve.

2.2. Mixture proportions

The mixture proportions of concrete are summarized in Table 1. The target compressive strength of concrete was designed as 30 N/mm^2. A reasonable amount of cementitious materials of 430 kg/m^3 was used. High constant water to binders' ratio (W/B) of 0.56 was used for all concrete mixtures in order to maintain the slump of the fresh concrete and to enhance workability so that super plasticizer could be avoided. The ratio of fine aggregate to coarse aggregate was fixed at 37:63 by volume.
20% of palm oil fuel ash (Mixture POFA20) was used to replace the cement in the concrete design mix. Mixture POFA20 was used for all of the specimens treated with different curing methods. This was based on the previous studies where replacing cement with 20% of palm oil fuel ash gives the highest compressive strength (with minimal drop in the strength compared to normal concrete), and the optimum concrete performance.
The control mixture was produced to compare the final compressive strength of normal concrete and POFA concrete at the age of 28 days. Trial mix for the normal concrete was carried out prior to the concrete casting to determine its strength and workability.

2.3. Concrete mixing and casting

A total of 45 cube and 30 prism specimens were prepared. In addition, a control mixture concrete (Control) was treated with WC and three cubic specimens were prepared to determine the average compressive strength of the concrete at the age of 28 days.
Once concrete mixed, slump test was carried out to measure the workability of the fresh concrete. The concrete was then cast into 100 mm cube and 100x100x500mm prism moulds. Subsequently, specimens were vibrated and compacted according to standard procedures, and kept for 24 hours in the mixing laboratory before they were demoulded and transferred to different curing environments according to their respective curing conditions.

2.3. Curing methods

The effect of the curing method on the strength of POFA concrete is the main objective of this study especially the early strength due to the growing importance in the precast industry. Five different feasible curing methods were carried out, each with different temperature and humidity conditions. The curing methods are WC, AC, PC, OWC, and OAC.
Water Curing (WC) is the most common curing method. The specimens were placed in a water tank in order to maintain the temperature and to provide high humidity. This curing condition allowed the hydration of the cementitious matrix to be best promoted.
For air curing (AC), the specimens were left in the laboratory without given any specific treatment during its hydration phase. The ever-changing surrounding temperature and humidity would have high influence on the concrete strength.
The specimens were wrapped with plastic in airtight condition in plastic-wrapped curing (PC). This curing method prevents the water inside the specimens from evaporating from the surface.
In oven curing, the specimens were placed inside a high temperature environment in order to accelerate hydration. In this study, the oven was preheated for 2 hours before the specimens were placed inside the oven for 16 hours under 60^{0}C. Thereafter, the oven was switched off and the specimens were left to cool inside the oven for 2 hours. Once the specimens were taken out, they were placed either inside water tank for water curing (OWC) until the day of testing or just placed in the laboratory for air curing (OAC).

Table 1: Chemical compositions and physical properties of cement

Test		Units	Specification MS 522-1:2007 (42.5N)	Test Results
Chemical Composition				
Insoluble Residue		%	≤5.0	0.4
Loss on Ignition (LOI)		%	≤5.0	3.2
Sulfate Content (SO_3)		%	≤3.5	2.7
Chloride (Cl^-)		%	≤0.10	0.02
Physical Properties				
Fineness (According to Blaine)		m^2/kg	-	345
Setting Time (Initial)		mins	≥60	130
Soundness		mm	≤10	1.0
Compressive Strength (Mortar Prism) (1:3:0.5)	2 days	MPa	≥10	29.7
	28 days	MPa	≥42.5; ≤62.5	48.9

Table 2: Concrete mixture properties

Mixture proportions (kg/m3)							
Concrete type	Cement	POFA	Fine agg.	Coarse agg.	Water	W/B	Slump (mm)
POFA20	344	86	650	1110	240	0.56	185
Control	430	0	650	1110	240	0.56	180

2.5. Testing

All tests were setup and carried out in accordance to standard testing procedures for compressive test and four points flexural test. For each variable, a mean average (3 specimens for compressive testing and 2 specimens for flexural testing) was determined.

3. Analysis of results and discussion

3.1. Compressive strength

A summary of compressive strength test results of POFA20 treated with different curing methods, at the age of 3, 7 and 28 days are presented in Table 3 and Figure 1. Each of these results is the average value of three cube specimens.

It is noted that the compressive strength of POFA20-WC at the age of 28 days was lower than Control-WC by 20%. This was expected as previous studies have shown that replacing cement with palm oil fuel ash would definitely reduce the strength of the concrete unless high degree of fineness of palm oil fuel ash was used to enhance its pozzolanic property [6, 11, 12]. In this study, 300µm palm oil fuel ash used is rather categorized as large size. Target compressive strength could still be achieved by using 300µm size of palm oil fuel ash if the water to binder ratio was reduced to a certain degree such as 0.20 and by adding super plasticizer to maintain its workability, which has previously been shown by Ahmad et al. [15]. However, this mix design has not been used in this study as the core is to investigate the effect of different curing methods on the strength of palm oil fuel ash concrete.

Figure 1 shows that POFA20-AC and POFA20-PC possess low compressive strength with the former being the lowest. POFA20-WC shows the highest compressive strength at the age of 28 days while POFA20-OAC shows the highest compressive strength at the age of 7 days.

Concrete needs suitable temperature and high humidity in order for the hydration phase to carry out successfully to achieve its target strength and so does POFA concrete. With AC, POFA20 is exposed to dry surrounding which causes significant water loss from the concrete and affects the hydration process. Once the water within the concrete is used up, the hydration process can no longer proceed even though the process is not fully completed and hence, resulting in low compressive strength. However, the compressive strength of POFA20-AC would be different from place to place and day to day because it is mainly affected by the weather and environment conditions. The results show that the compressive strength of POFA20-AC is 28% lower than POFA20-WC at the age of 28 days.

POFA20-PC gives a slightly better result than POFA-AC but not better than POFA-WC. The POFA20-PC specimens were wrapped in airtight condition that largely reduces the water evaporation from the concrete surface and provides sufficient water for the cement and palm oil fuel ash to undergo hydration process. However, when the water is used up, there will be no external water source which eventually affects the compressive strength because the hydration process cannot proceed without water. In general, both of POFA20-AC and POFA20-PC give quite low compressive strength throughout the concrete age.

Table 2: Compressive strength results

Type of concrete	Curing Method	Concrete compressive strength (MPa)		
		3 days	7 days	28 days
POFA20	Water Curing (WC)	18.36	20.67	24.45
	Air Curing (AC)	11.64	13.65	17.59
	Plastic-wrapped Curing (PC)	15.18	17.36	20.78
	Oven + Water Curing (OWC)	20.32	20.20	23.19
	Oven + Air Curing (OAC)	20.06	21.11	23.17
Concrete	Water Curing (WC)			30.28

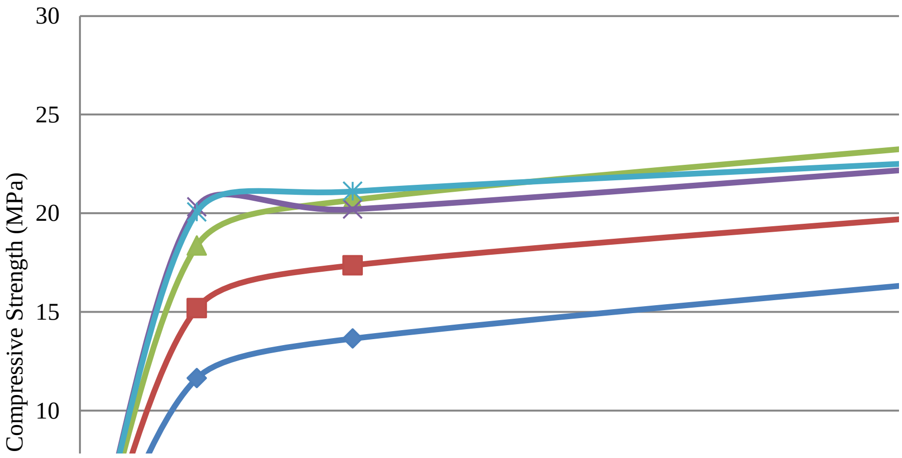

Fig. 1: Compressive strength of POFA20 with different curing methods.

Both of POFA20-OWC and POFA20-OAC generally achieved the highest compressive strength at the early stage as observed from Figure 1, i.e., age of 3 days. Both of POFA20-OWC and POFA20-OAC are 10% higher in compressive strength than POFA20-WC at the age of 3 days. The high early compressive strength was stimulated by the heat from the oven which accelerates the compressive strength gained by POFA concrete. The heat from the oven gave high temperature which extends the hydration process and causes an increase in the early strength. This is because calcium silicate hydrate, C-S-H gel, the binding phase in concrete, is formed quicker with the aid of heat from the oven. Therefore, if higher temperature and longer duration was used, the early compressive strength gained by the POFA concrete would be higher due to the increase in the rate of hydration in concrete.

3.2. Flexural strength

The flexural strength of POFA20 concrete with different curing methods at the age of 3, 7 and 28 days are presented in Table 4 and Figure 2. Each of these results is the average value of two prism specimens. Similar to the compressive strength, POFA20-AC possesses the lowest flexural strength. POFA20-WC has the highest flexural strength at the age of 28 days. POFA20-OAC has the highest flexural strength at the age of 7 days. The trend of the flexural strength gained by POFA20 with different curing methods is similar to that of the compressive strength.

Table 3: Flexural strength results of POFA20 with different curing methods

Type of concrete	Curing Method	Failure loads (kN}			Concrete flexural strength (MPa)		
		3 days	7 days	28 days	3 days	7 days	28 days
POFA20	Water Curing (WC)	8.5	10.7	14.6	2.55	3.21	4.38
	Air Curing (AC)	5.5	7.0	9.0	1.65	2.1	2.7
	Plastic-wrapped Curing (PC)	7.5	9.9	11.7	2.25	2.97	3.51
	Oven + Water Curing (OWC)	12.4	12.3	14.4	3.72	3.69	4.32
	Oven + Air Curing (OAC)	12.1	12.9	14.3	3.63	3.87	4.29

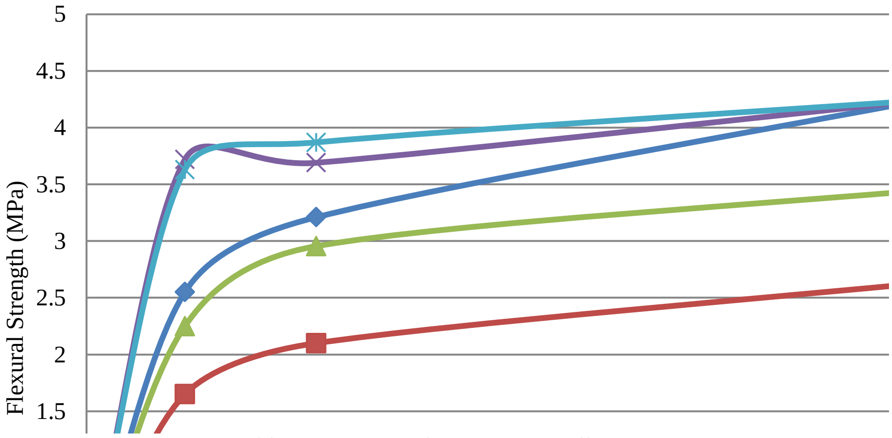

Fig. 4: Comparison of flexural strength of POFA20 with different curing methods.

4. Conclusion

The main objective of this paper is to study the effect of different curing methods on the compressive and flexural strengths of palm oil fuel ash concrete. The curing methods used in this study are water curing, air curing, plastic-wrapped curing, oven with water curing and oven with air curing. The results show the potential of using oven curing procedure to achieve high compressive and flexural strength at early stages. However, the rate of hydration starts to decrease at later stages and the hydration by-products created during the rapid initial hydration causes the concrete structure to be less compact and more porous and eventually causing the compressive strength of the oven cured specimens to be lower than the compressive strength of the water cured specimens at the age of 28 days. Water cured specimens possess the highest compressive and flexural strength at the age of 28 days compared to other curing methods and this is why it is still the most common and most popular concrete curing method amongst all and it saves energy as well. Oven curing method would be ideal for the precast industry due to its high early strength but an important attention must be paid to its strength at the later age.

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